The POWER of position

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Vibration levels were not the indicator of degraded turbine generator bearings at Florida Power & Light's St. Lucie Plant. Although the vibration diagnostics indicated that a problem was developing, vibration levels did not increase to unacceptable levels. Shaft position information, available through Bently Nevada proximity probes, provided the supporting information that convinced plant personnel to inspect the damaged bearings.

The machine

The St. Lucie Plant, a nuclear facility located on Hutchinson Island off Florida's southeast coast, has two Westinghouse 1000 MVA turbine generators. Each machine is composed of one high pressure turbine, two low pressure turbines, a hydrogen-cooled main generator, and an air-cooled exciter. Nine fluid film bearings and one thrust bearing assembly support this machine.

Bearings #7 and #8 support the generator rotor, and Bearings #8 and #9 support the exciter rotor. Bearing #9 also supports an overhung fan and permanent magnet generator (Figure 1). None of these bearings has an oil lift system.

The generator feet are supported by foundation plates. The hold-down bolts use a sleeve/washer arrangement, with 1-10 mils clearance between the washer and foot. The generator also has transverse and axial keys between the frame and foundation that allow the generator to shift (from thermal and pressure forces) while keeping the frame properly aligned.

Instrumentation

A Bently Nevada 7200 Turbine Supervisory Instrumentation System monitors the turbines. Two Bently Nevada Dual Probes are mounted 90 degrees apart (XY) on each turbine bearing. Each Dual Probe contains two transducers: a proximity probe for shaft relative vibration and centerline position, and a velocity Seismoprobe® to measure casing vibration. Shaft absolute vibration can be obtained by adding the signals from the two transducers.

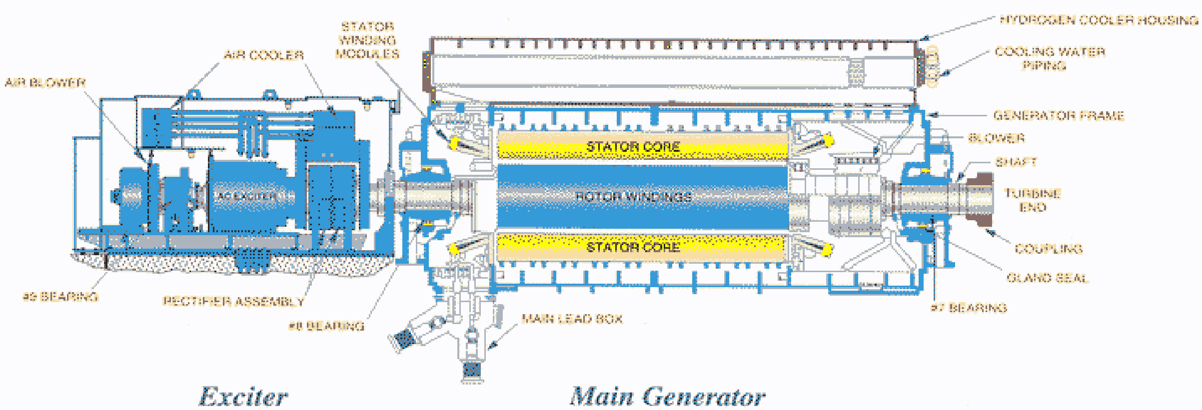


Figure 1

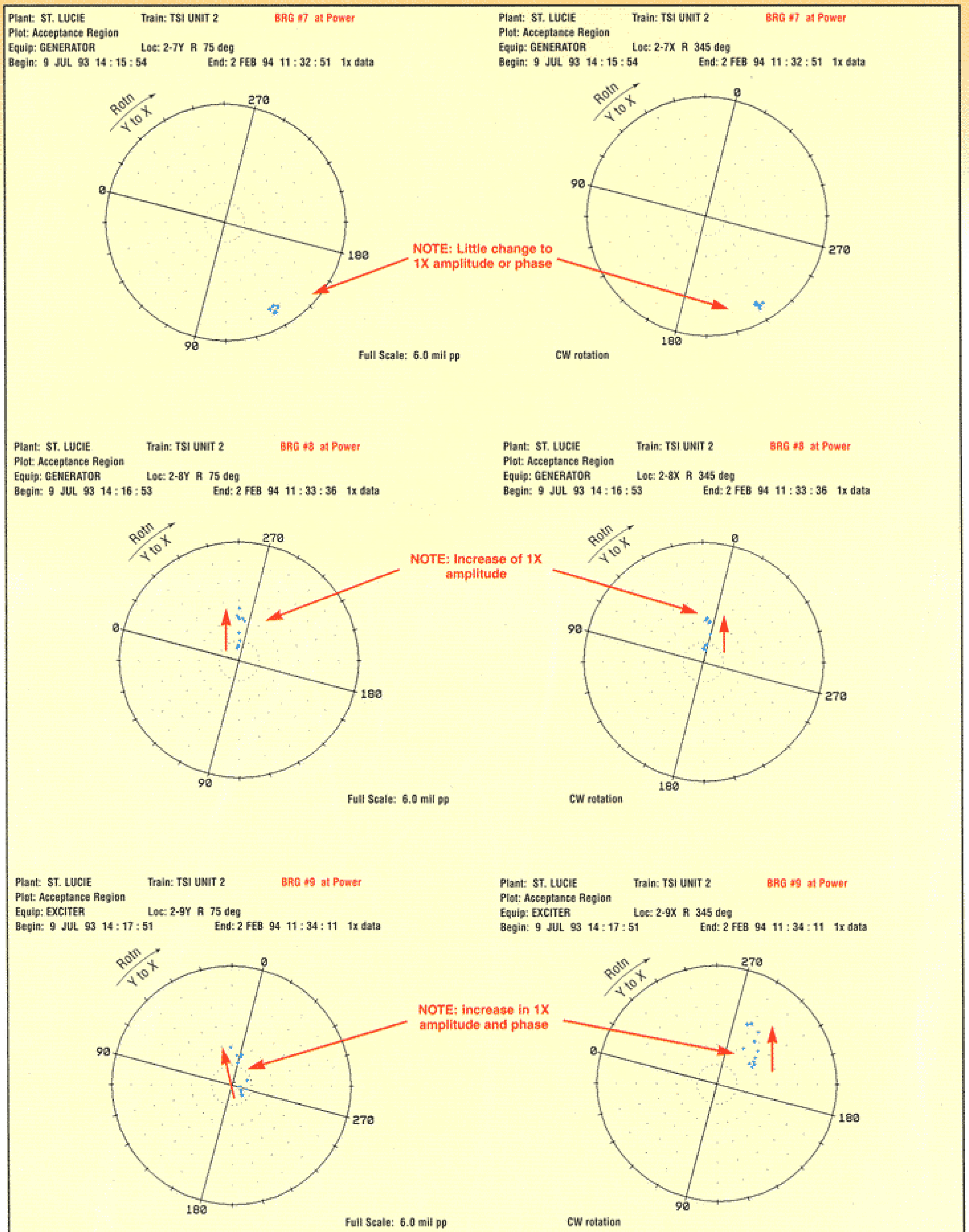


Figure 2
Acceptance region plots of Bearings #7, #8, and #9 vibration, X and Y probes, at power

Steady state vibration data is routinely collected approximately every two weeks by Predictive Maintenance personnel, using a Bently Nevada Snapshot® Plus System. Transient vibration data is normally collected using a Bently Nevada ADRE® 3 System and 108 Data Acquisition Instrument during initial startups after a refueling outage and during coastdowns prior to refueling.

Machine save

On November 2, Unit 2 was manually shut down for a short time to correct a temperature excursion. Analysis of vibration data routinely taken after restart identified some changes to the vibration signature of the exciter (Table 1 and Figure 2).

Steady state vibration data showed:

1) Bearing #7: The 1X relative vibration patterns did not significantly change.
2) Bearing #8: The 1X relative vibration levels increased 1.9 mils to 2.6 mil pp and stabilized at this increased level. The 1X phase angles didn't significantly change. *More significantly, the shaft position had immediately shifted 6 mils horizontally.*
3) Bearing #9: The 1X relative vibration levels increased by 1.2 mil pp over the next 15 weeks to 3.4 mil pp.

   The 1X phase angle of the Y and X vibration signals increased 31 degrees and 108 degrees, respectively. *The shaft position also shifted 6 mils, but in the opposite direction from Bearing #8, over the next several weeks (Figure 3).*

Comments:

1) The exciter operates below the first balance resonance (critical). Below the first balance resonance, an increased 1X magnitude and phase value would be consistent with reduced rotor system stiffness.
2) A 6 mil change in the turbine generator's shaft position was unusual. Typical shaft position changes at 100% power are rarely more than 2 to 3 mils.
3) The bearing oil and metal temperatures after restart didn't significantly change.

Although the available information indicated that the bearing had "softened," allowing the exciter shaft position to shift and vibration to increase, the vibration did not yet increase to unacceptable levels.

No significant work had been scheduled on the generator or exciter during an upcoming February outage. Therefore, plant management was reluctant to spend an estimated $250,000 to disassemble the generator and exciter bearings without a solid reason. Additional machinery data would be required to assess the need to perform a bearing inspection.

Table 1. Relative 1X uncompensated vibration
(Data in mils pp at degrees phase lag)

	Before shutdown	After shutdown
Probe	10/22/93	11/18/93
7Y	5.2 @ 133°	5.0 @ 136°
7X	5.1 @ 225°	5.2 @ 226°
8Y	0.7 @ 288°	2.6 @ 284°
8X	0.7 @ 11°	2.1 @ 11°
9Y	2.2 @ 228°	3.4 @ 259°
9X	0.6 @ 253°	1.1 @ 1°

Notes: 1. Unit alarm actuated on Nov. 2, 1993
2. There was a 3 to 4 mil runout/slow roll (due to coupling assembly anomalies) at Bearing #7 that had been previously identified during the initial startup for this fuel cycle.

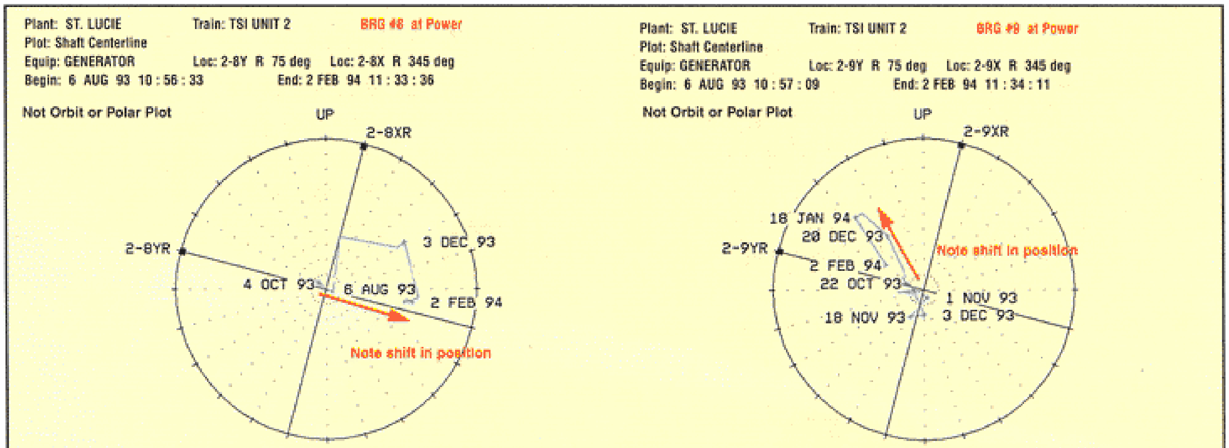


Figure 3
Change in shaft centerline position at Bearing #8 and #9.

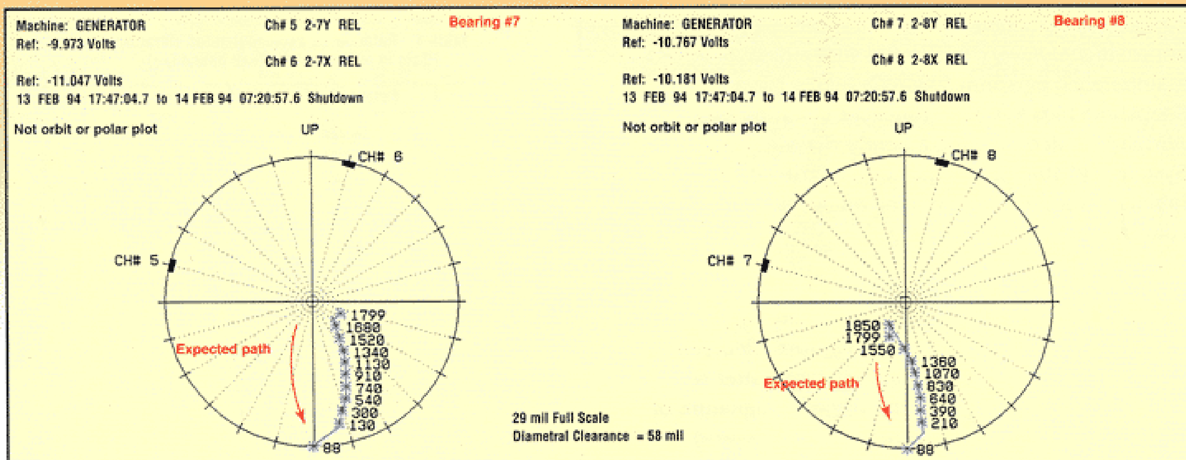


Figure 4a
Shaft centerline plot of Bearings #7 and #8 coastdown with damaged bearing

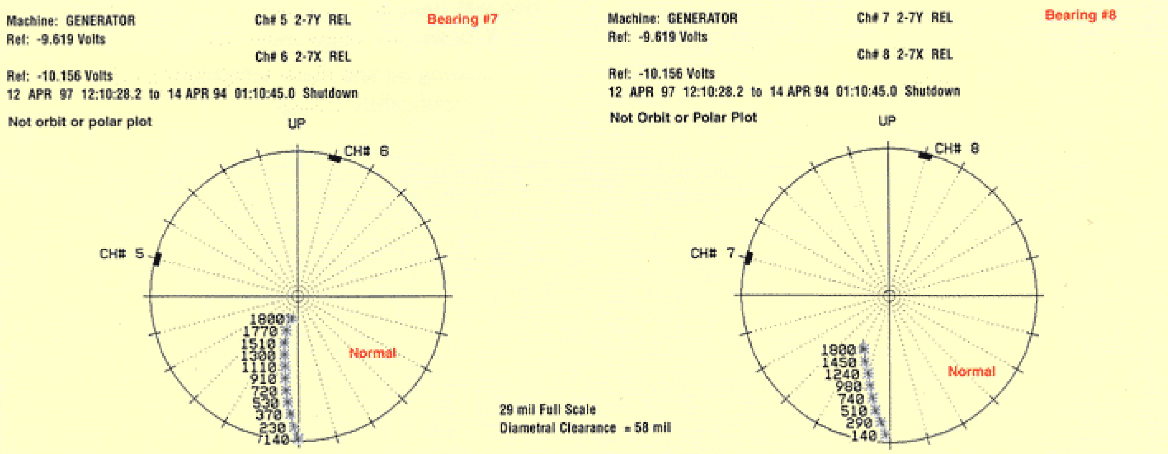


Figure 4b
Shaft centerline plot of Bearings #7 and #8 normal coastdown with undamaged bearings

Transient vibration data showed:

The shaft centerline coastdown path (Bearings #7 and #8) approached the turning gear position from the wrong quadrant. (Figure 4a). This pattern was not seen on previous coastdowns or startups (Figure 4b), and was a good indication that bearing damage had occurred. The damaged bearing surface modified the direction of the hydrodynamic forces in the bearing, which resulted in a different shaft position angle.

The shaft position on turning gear (at Bearings #7, #8 and #9) was also 6 mils lower than was observed during the initial startup for this fuel cycle. This was determined by comparing gap voltage readings, while the unit was on turning gear, at the start and the end of the cycle.

Physical measurements were taken to verify the shaft position data. Oil seal clearance readings were taken at Bearings #7, #8 and #9 with the machine cold. Measurements indicated that the expected 6 mils shaft clearance at the bottom of the shaft wasn't present.

The available machinery data indicated a high probability of degradation at Bearings #7, #8 and #9, and the decision was made to perform a bearing inspection. Each bearing was found to be wiped. The increased clearances led to the changes in position documented in the steady state and transient vibration

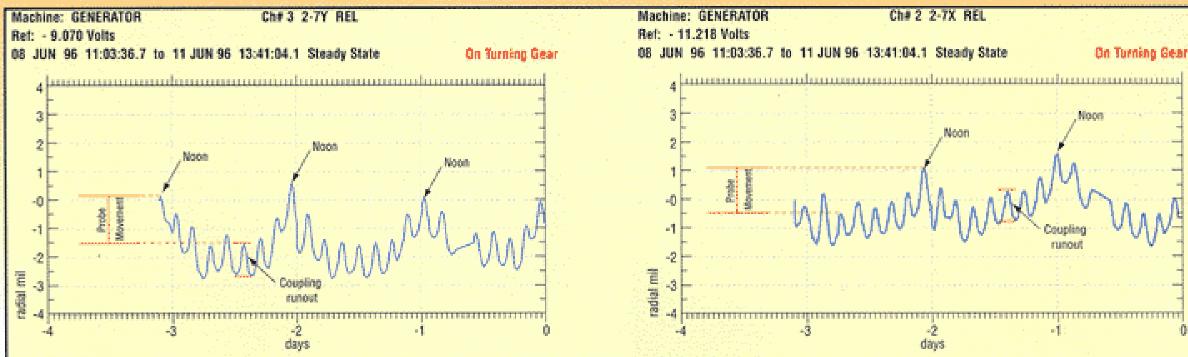


Figure 5a
Normal flexure, on turning gear, of generator shell due to hydrogen cooler.

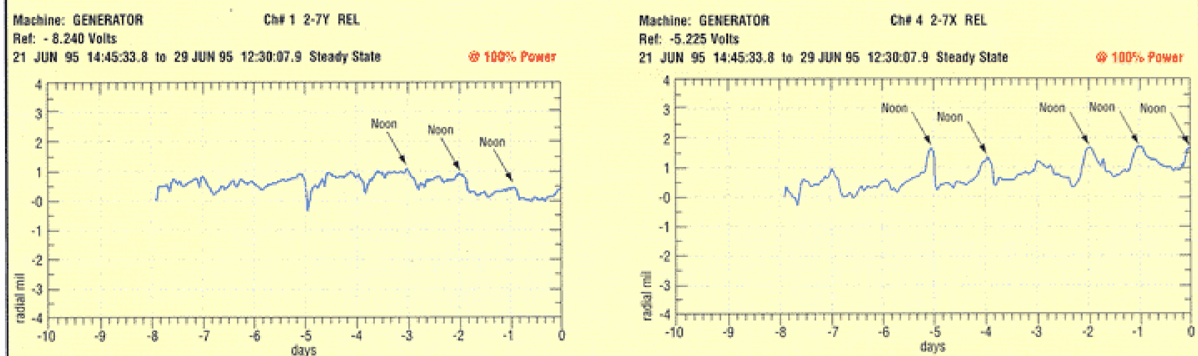


Figure 5b
Normal flexure, at 100% power, of generator shell due to hydrogen cooler.

information. In addition, Bearing #7 had ingested a small washer, which gouged a chunk out of the babbitt material, and then became imbedded (Photos 1 & 2).

As long as an oil wedge forms to lift the rotor, even damaged fluid film bearings can sustain normal operation. Therefore, it was possible that this unit could have been put online. However, there is no oil lift system for these bearings, and, during a typical 18 month cycle, the machine would most likely be on turning gear several times. The potential cumulative damage to the bearings would have significantly increased the possibility of a mid-cycle failure. Therefore, this early detection at the start of an outage had very likely prevented either an outage extension or forced outage, with an ensuing loss of production.

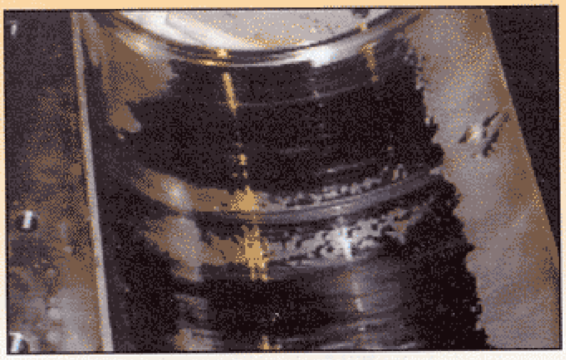
Don't jump to conclusions

Before you start thinking that all gap voltage changes are signs of shaft position changes, however, you should read the following story.

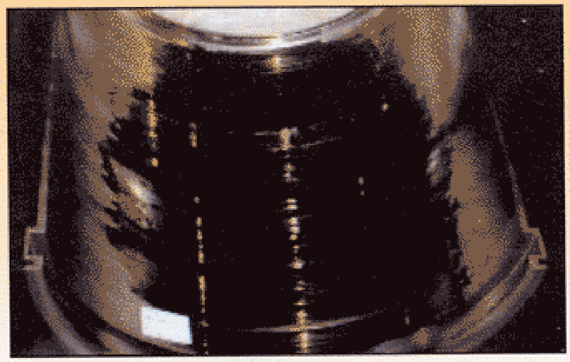
Following a subsequent unit shutdown due to high generator gas temperatures, the machine was placed on turning gear. During the night, probe gap voltage values indicated a 4 to 6 mil drop in generator rotor position had occurred. This change was similar in magnitude to the previous drop during coastdown.

In contrast, trended gap voltage readings showed that the generator normally goes through a 1 to 2 mil flexure during a 24-hour cycle, both on turning gear and in normal operation, peaking at midnight and returning to normal at noon (Figure 5a and 5b).

Although vibration patterns during operation had been stable, oil seal clearance readings after the high generator temperature shutdown, before the machine was cold and stable, again showed that the expected clearances were significantly reduced. To be on the safe side, gap voltage levels were tracked for the next few hours. During the day, the apparent shaft position returned to normal, which was confirmed by additional oil seal clearance measurements.



Bearing #7



Bearing #8

The likely scenario that explains this data is that the hydrogen coolers, located on the top of the generator, cool the upper shell more than the lower shell. This should create an upward flexure that would lift the probes away from the shaft (as the generator bearings are internal, these probes are mounted to the generator shell). Later, the uneven temperature distribution would be alleviated by thermal heating from the sun and the apparent shaft position would return to normal.

This story shows that you need to obtain supporting data, and to be sensitive to thermal transients, before making a call solely based on subtle gap voltage changes.

Conclusions

Shaft position plots are a powerful tool for problem detection and identification. This data represents the "dial indicator" ability of the proximity probe. In this particular case, the operating vibration levels didn't become excessive, but something was certainly happening. The shaft centerline plots were the defining data sets that identified the problem.

New Demo Room for customers and employees

When you visit our Research and Training facility in Minden, Nevada, you will now notice two large consoles in the lobby. These consoles are connected to various machines which are running 24 hours per day. Customers, students attending our technical training courses and Bently Nevada employees are encouraged to sit down at the consoles and view these machines using the latest versions of Bently Nevada Software.

Products currently on the consoles are Machine Condition Manager™ 2000, Data Manager® 2000, Trendmaster® 2000, and 3500 Monitoring System Software. These consoles provide the opportunity for you to "test drive" Bently Nevada products.